

# Study on the Impact of Green GDP Accounting System on Climate - Based on Integrated Evaluation and Markov Modelling

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**Abstract.** GDP does not consider the impact of economic development on environmental hazards and resource consumption. Therefore, our team developed a reliable model and utilized the GGDP to assess the fiscal health of countries with the hope that governments will adopt policies to mitigate the impact of economic development on the global climate. To measure the financial health of each country's system, we selected raw data on five critical factors for 50 countries from 2010 to 2020. We then validated the data distribution patterns and selected the 80% quartile as the healthy range for each indicator. We used analytic hierarchical process (AHP) to determine the weights of each hand. Finally, we introduced the concept of the Economic Health Index (EHI) concept, which represents an economy's actual health. We also use Markov chains to predict the future global climate impact of flexible government policy measures to promote GGDP growth after GGDP replaces GDP. To measure the effect on global climate, we use the achievement of the GHG emissions and energy consumption targets agreed upon by countries in the Paris Agreement.

**Keywords:** Green GDP, AHP, Markov Chain.

## 1. Introduction

GDP is an essential indicator to measure the economic health of a country. However, it does not consider the impact of economic development on environmental hazards and resource consumption. GGDP is proposed as a new indicator to stimulate governments to adopt specific environmental protection measures[1-2].

This paper analyzed several primary accounting methods for GGDP and decided to synthesize them to build our model.

A country's economic health should reflect its financial strength and the extent to which it uses and protects its natural resources[3]. Therefore, our team developed a reliable model and utilized the GGDP to assess the fiscal health of countries with the hope that governments will adopt policies to mitigate the impact of economic development on the global climate. To measure the financial health of each country's system, we selected raw data on five critical factors for 50 countries from 2010 to 2020. We then validated the data distribution patterns and selected the 80% quartile as the healthy range for each indicator. We used analytic hierarchical process (AHP) to determine the weights of each hand[4-5]. Finally, we introduced the concept of the Economic Health Index (EHI) concept, which represents an economy's actual health. We also use Markov chains to predict the future global climate impact of flexible government policy measures to promote GGDP growth after GGDP replaces GDP. To measure the effect on global climate, we use the achievement of the GHG emissions and energy consumption targets agreed upon by countries in the Paris Agreement. The data for this article was taken from the web site <https://data.worldbank.org.cn/>.

## 2. GGDP model building and solving

### 2.1. Concept of GGDP

The green gross domestic product (green GDP or GGDP) is an index of economic growth with the environmental consequences of that growth factored into a country's conventional GDP. Green GDP monetizes the loss of biodiversity and accounts for costs caused by climate change[6].

### 2.2. Accounting Method Filtering

#### • GGDP

GGDP accounting consists of three components: gross domestic product, environmental degradation cost, and ecological damage.

(1) Environmental degradation cost: air pollution, water pollution, and soil pollution can lead to environmental degradation. The price of environmental degradation caused by air pollution mainly includes the cost of air pollution treatment and the increase in living and cleaning costs[7-8].

(2) Cost of ecological damage. The cost accounting of environmental damage in the basin mainly focuses on the loss of ecological regulation services caused by humans' unreasonable use of forests, grasslands, wetlands, farmlands, and other ecosystems.

$$GGDP = GDP - EDC - edc \quad (1)$$

$$EDC = EnDCa + EnDCw + EnDCs \quad (2)$$

$$edc = EcDCf + EcDCg + EcDCw + EcDCa \quad (3)(1)$$

EnDC is the environmental degradation cost, EnDCa is the environmental degradation cost of air pollution. EcDCw is the environmental degradation cost of water pollution, EnDCs is the cost of soil pollution and environmental degradation, EcDCf is the damage loss of forest ecosystem, EcDCg is the damage loss of grassland ecosystem, EnDCw is the damage loss of wetland ecosystem, and EcDCa is the damage loss of farmland ecosystem.

#### • GeGDP

The value of GGDP is smaller than that of GDP, that is, the value of GeGDP is equal to subtracting the following two values on the basis of the current GDP accounting value: one is called "resource depletion cost", the other is called "environmental degradation cost"[9].

$$GeGDP = GDP - RDC - edc \quad (4)$$

#### • MEWGDP

MEWGDP is a model that measures annual real household consumption, called the Measure of Economic well-being. MEW adjusts GDP to include the value of leisure time, unpaid work and environmental damage. The values of the Ministry of Sustainable Water and Power (MEW-S), whose work is a precursor to more complex sustainable development measures, are also defined[10].

### 2.3. Main Factors

To achieve the replacement of GDP with GGDP as the primary measure of the country's economic health, we need to make a new and reasonable assessment of the actual state of the country's economy, and we need to consider not only GDP as the primary indicator, but also to judge its impact on natural resources and climate. Similar to the definition of physical health, the health of a system refers to its ability to function correctly and to respond to external changes. A healthy national economic system not only has the function to indicate its financial strength but also to repair and renew itself according to the changes in natural resources and climate and to act back on them to achieve sustainable development of resources.

Based on the above definition, we have developed five factors to measure the economy's health after considering the use of natural resources, which are described below.

- Heart

GDP is the final result of the production activities of all resident units in a country (or region) over a certain period. It has long been recognized as the core indicator of national economic accounting and an essential indicator of a country's or region's financial status and development. In our new economic system, it deserves to occupy the heart position.

- Resource

Resource is an evaluation of the level of natural resource holdings in different countries. Its content is vibrant, and we have chosen four indicators to describe it: total freshwater, agricultural land, forest coverage, land and sea area. The development of society and the progress of science and technology require the development and use of more and more natural resources. This indicator allows for determining the maximum total amount of natural resources available to the country.

- Expense

Expense is a comprehensive assessment of national resource consumption in each country, which is described as seven indicators: loss of fixed capital, agricultural value-added, use of renewable energy, energy depletion, mineral depletion, forest depletion and population density. Fixed capital is the loss in use value and value caused by the use of resources in production and processing and the impact of natural forces. Agricultural value-added is the value added by agricultural, forestry, and fishery production. The use of renewable energy is the value added by the use of renewable energy. The use of renewable energy reflects the development of renewable energy sources and the efforts made by the country in the sustainability of resources; energy depletion, mineral depletion, and forest depletion are the three significant resource losses in the country's economic development. Population density is a reflection of the use of land resources.

- Emission

Emissions are a count of national contributions to global climate change in each country. According to the Kyoto Protocol, greenhouse gas emissions profoundly impact global climate change, and we have selected the emissions of six gases (CO<sub>2</sub>, CH<sub>4</sub>, N<sub>2</sub>O, HFCs, PFCs, SF<sub>6</sub>), which are subject to emission limits, as the total greenhouse gas emissions. In addition, with the increase in air pollution, PM<sub>2.5</sub> not only becomes a significant factor affecting global climate but also endangers human life and health.

- Diversity

Diversity is a measure of the national biological resources of each country. Biological resources are a valuable asset given by nature to each country. Following the UN Millennium Development Goals, we have selected the area of the reserve and the red list index<sup>[3]</sup> indicators to assess biodiversity.

## 2.4. Data Selection

We used the same dataset but different evaluation methods to evaluate health status and climate impacts. To assess health status, we will calculate the data weights and list the leading indicators, thus constructing a confidence interval similar to the pathology test.

The approach to assessing climate impacts is slightly different. We use the carbon reduction target agreed upon in the Paris agreement<sup>[4]</sup> as a measure of global climate change, divided explicitly into global greenhouse gas emissions and global energy consumption over the next 50 years after adopting the GGDP standard.

Below is a table of selected indicators. The letter 'P' in the Impact column indicates that the indicator positively impacts GGDP. 'N' refers to the opposite. Specific indicators can have a negative effect on the results when they are too high or too low.

When they are too high or too low, they can negatively affect the results, so we assign them the letter 'M'. Economic health indicators are shown in table 1.

**Table 1.** Economic health indicators

| Factor    | Indicator                | Symbol    | Unit | Impact | D.S |
|-----------|--------------------------|-----------|------|--------|-----|
| Heart     | GDP                      | $O_{1j}$  | \$   | M      | a   |
|           | Total fresh water        | $I_{1j}$  | Kg   | P      | a   |
| Resource  | Agricultural land        | $I_{2j}$  | %    | P      | b   |
|           | Forest coverage          | $I_{3j}$  | %    | P      | a   |
|           | Land and sea area        | $I_{4j}$  | %    | P      | c   |
|           | Loss of fixed capital    | $O_{2j}$  | \$   | N      | a   |
|           | Agricultural value-added | $O_{3j}$  | \$   | P      | c   |
| Expense   | Use of renewable energy  | $I_{5j}$  | Kt   | P      | b   |
|           | Energy depletion         | $I_{6j}$  | Kt   | N      | a   |
|           | Mineral depletion        | $I_{7j}$  | Kt   | N      | a   |
|           | Forest depletion         | $I_{8j}$  | Kt   | N      | a   |
|           | Population density       | $I_{9j}$  | %    | M      | b   |
| Emission  | Greenhouse gases         | $I_{10j}$ | Kt   | N      | a   |
|           | PM2.5 in air             | $I_{11j}$ | %    | N      | a   |
| Diversity | Area of the Reserve      | $O_{4j}$  | %    | P      | b   |
|           | Red list index           | $O_{5j}$  | -    | P      | d   |

*Note: D.S. is the abstract of data source. D.S. a is collected from World Bank World Development Indicators D.S. b is collected from the OECD. D.S. c is collect from ourdatainworld.org. D.S. d is collect from IUCN.*

The main contributors to climate impacts tend to be countries that are more developed in the economy or natural resources, we surveyed a random sample of these countries for their indicators from 2010 to 2020. The selected example of 50 is shown in table 2.

**Table 2.** Countries we selected

| Countries | 1         | 2              | 3           | 4            | 5                    |
|-----------|-----------|----------------|-------------|--------------|----------------------|
| 1         | Argentina | Czech Republic | Ireland     | New Zealand  | South Korea          |
| 2         | Australia | Denmark        | Israel      | Norway       | Spain                |
| 3         | Austria   | Egypt          | Italy       | Pakistan     | Sweden               |
| 4         | Belarus   | Estonia        | Japan       | Philippines  | Switzerland          |
| 5         | Belgium   | Finland        | Kazakhstan  | Poland       | Thailand             |
| 6         | Brazil    | France         | Lebanon     | Portugal     | Turkey               |
| 7         | Canada    | Germany        | Malaysia    | Russia       | Ukraine              |
| 8         | Chile     | Greece         | Mexico      | Saudi Arabia | United Arab Emirates |
| 9         | China     | India          | Mongolia    | Singapore    | United Kingdom       |
| 10        | Colombia  | Indonesia      | Netherlands | South Africa | United States        |

Here is a map(figure 1) showing the countries we have chosen.



**Figure 1.** Map for countries we selected

### 3. Models of GGDP health and climate impact

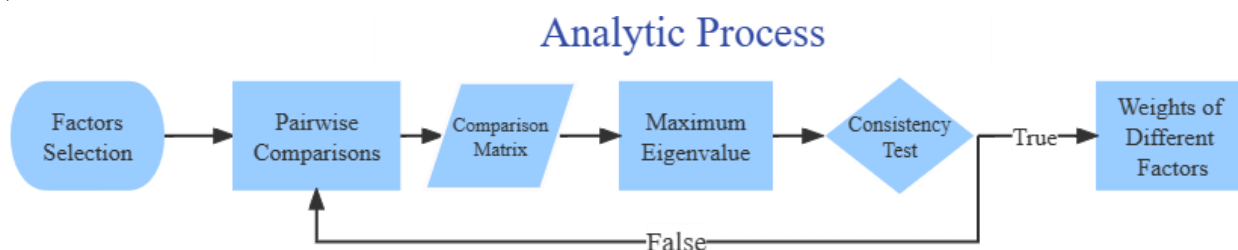
In this section, we build a GGDP health model and a climate impact model of a country's economy. Using these two models, we can perform a medical examination and diagnosis of each country's health and climate impacts. We can describe this process in the following diagram.

#### 3.1. GGDP Health Model

During a physical examination, the doctor usually checks the patient's various indicators and determines whether they are within the normal range. Determine whether they are within the normal range or not. These indicators have different weights, and those with larger weights have a greater impact on health status, while those with smaller weights have a relatively smaller impact, and we use a similar approach to measure the health status of the economy. Based on the previous assumptions, we determine the corresponding health range of each indicator and use the Analytic Hierarchy Process to determine the weight of each indicator. Through these analyses, we will give the overall health and the health of each factor.

#### 3.2. Determine the Weight of Indicators

The primary method we used to determine the weights was the analytical hierarchy process (figure 2).



**Figure 2.** Our analytic process

Analytic Hierarchy Process (AHP) is an accurate approach for quantifying the weights of decision criteria, widely used in different decision situations, in fields like government, business, healthcare, shipbuilding, industry and education . In our analysis, we use this method to determine weights of different main factors. Similarly, we determine the weights of different indicators in each factor. The following are the steps.

- Factors selection

We have selected several main factors previously. For each main factor, we have chosen some indicators as well.

- Pairwise comparisons between different factor

According to pairwise comparisons, we establish priorities among the factors. We think that the importance of main factors satisfies the following relationship:

$$GDP > \text{Natural resource appropriation} > \text{natural resource damage} \approx \text{greenhouse gas emissions} \geq \text{biological resources}$$

- Calculation of comparison matrix

With the relationship discussed before, we get our comparison matrix  $(b_{ij})_{5 \times 5}$

$$B = \begin{bmatrix} 1 & \frac{1}{3} & \frac{1}{4} & \frac{1}{7} & \frac{1}{9} \\ 3 & 1 & \frac{1}{3} & \frac{1}{3} & \frac{1}{5} \\ 4 & 3 & 1 & 1 & \frac{1}{5} \\ 7 & 3 & 1 & 1 & \frac{1}{2} \\ 9 & 5 & 5 & 2 & 1 \end{bmatrix} \quad (5)$$

Where  $F_i$  for  $i = 1, 2, \dots, 5$  represent heart, resource, expense, emission, diversity respectively.

- Consistency Test

We can calculate the eigenvalues and eigenvectors of the matrix before. Next we need to perform consistency test with the maximum eigenvalue  $\lambda_{\max}$ .

$$CI = \frac{\lambda_{\max} - n}{n - 1} \quad (6)$$

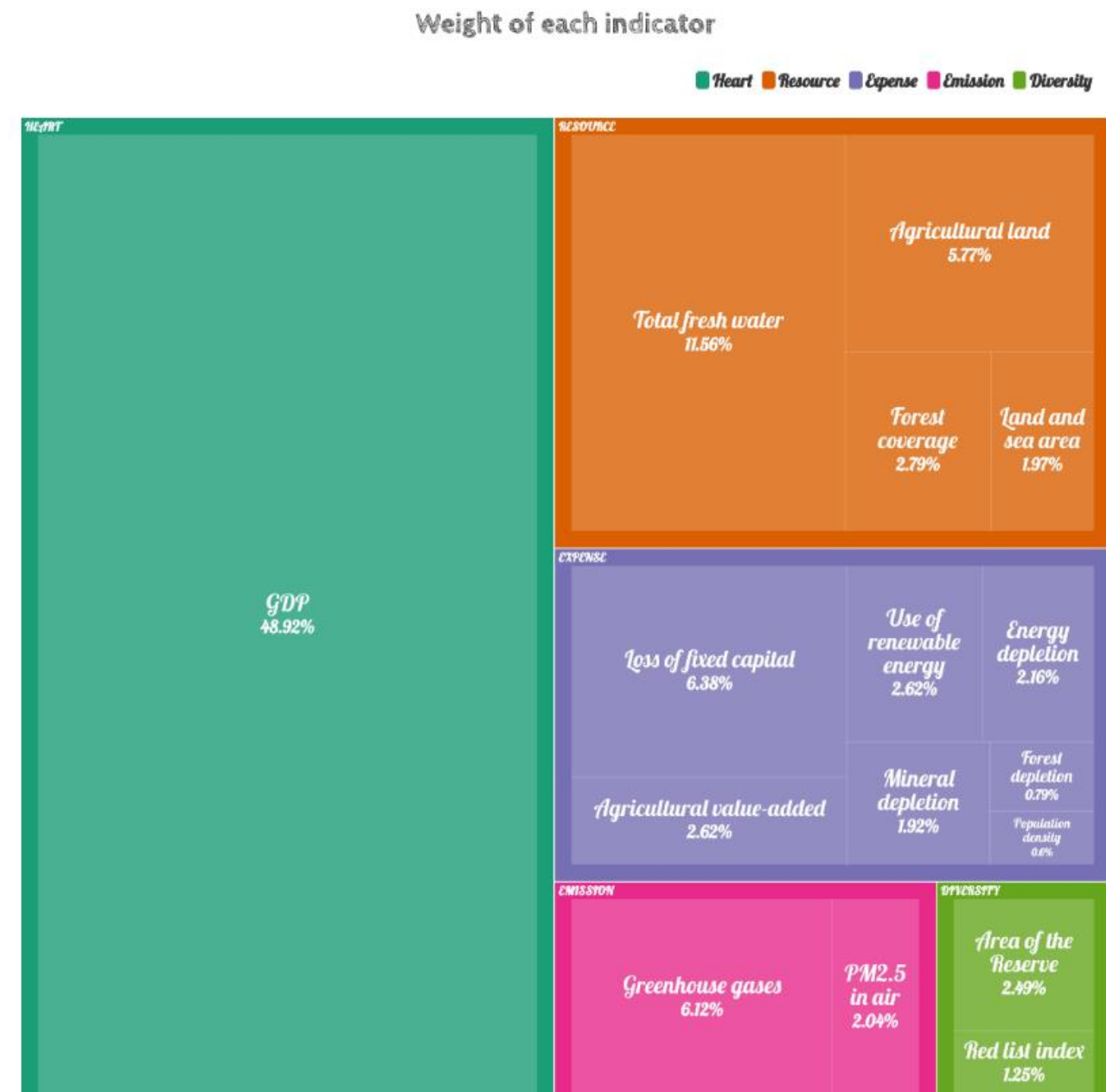
$$CR = \frac{CI}{RI} \quad (7)$$

According to the calculation above, CR of the judgment matrix is  $CR = 0.03841 \leq 0.1$ , thus the comparison matrix is acceptable.

- Calculation of weights Passing the consistency test

we can get the weights of main factors by the eigenvector corresponding to the maximum eigenvalue, they are as follow: heart(0.4892), resource(0.2209), expense(0.1709), emission(0.0816), diversity(0.0374).

Using the same method, we obtain the weights of the different indicators for each factor, as shown in the figure 3.



**Figure 3.** Weight of indicators

The weighted analysis allows us to obtain the ranking of each indicator by weight. The top-ranked indicators are called primary indicators, which considerably impact overall health. The more down-rated indicators are called secondary indicators, which have little impact on overall health, but we cannot ignore their cumulative effect.

### 3.3. Select Health Range

We fixed the economic health ratio by analyzing the GDP rankings overtime at 0.8. This suggests that 80% of the economic population is healthy. Based on these assumptions, We developed the following principles for selecting health ranges.

- Positive indicators

The sample data from the highest to the lowest 80% quartile were selected as the estimators of the overall lower limit.

- Negative indicators

The sample data from the low to the high 80% quartile was selected as the estimator of the overall upper bound.

• Interval Indicators

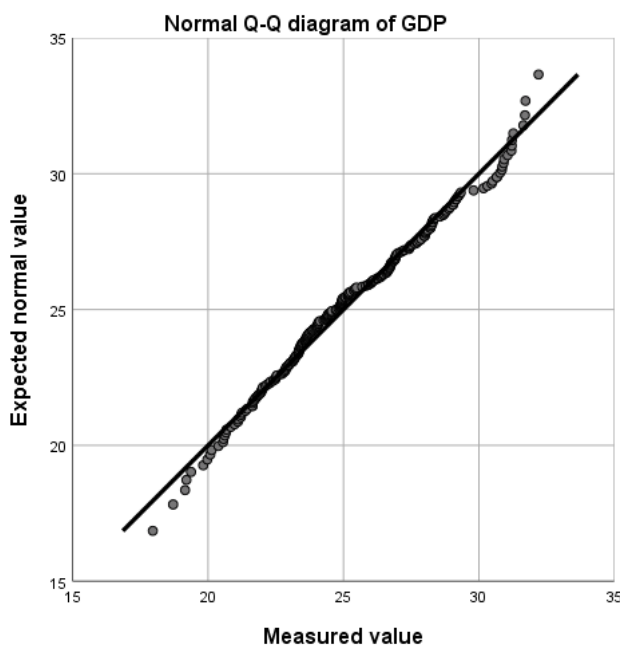
Estimate the distribution pattern of the population through the sample and determine the intervals. We found the range of health corresponding to the easy positive and negative indicators. Hence, the distribution pattern of the interval indicators needs to be considered: GDP and population density. By plotting the frequency histograms of these two indicators, we found that they have a pattern similar to the normal distribution. To test this conjecture, we tested these two indicators with SPSS using the Kolmogorov - Smirnov (K-S) test. Due to space limitations, we will not discuss the detailed principles of the K-S test here. Instead of discussing it here, only the results are shown.

At the significance level  $\alpha = 0.05$ , we obtained the following results of the K-S test for both indicators (table 3). Since the significance levels of both hands are higher than  $\alpha$ , we can conclude that they both pass the K-S test.

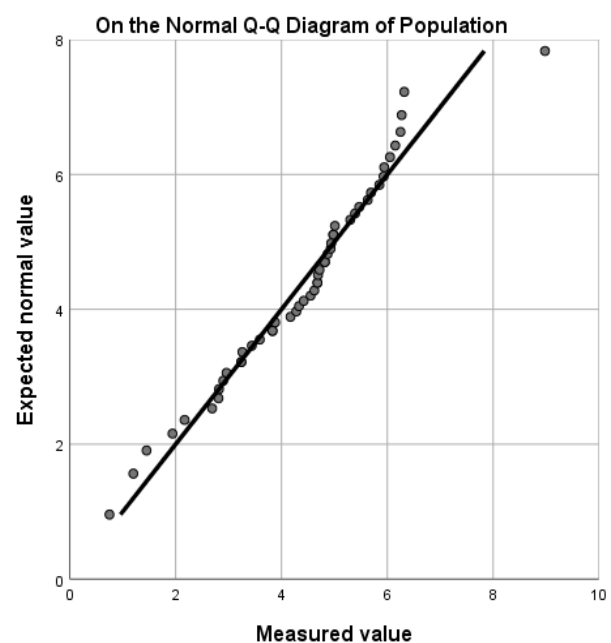
**Table 3.** Single sample Kolmogorovs-Minov test

|                                     | Population density | GDP     |
|-------------------------------------|--------------------|---------|
| abs                                 | 50                 | 245     |
| Normal parameter                    | Average value      | 4.3942  |
|                                     | SD                 | 1.53211 |
| Extreme difference                  | Absolute value     | 0.1     |
|                                     | Positive value     | 0.084   |
|                                     | Negative value     | -0.1    |
| Inspection statistic                | 0.1                | 0.06    |
| Progressive significance(bilateral) | .200               | 0.031   |

Figure 4 and figure 5 are the Q-Q plot of the two data to verify the correctness of the results. We can see that the data points of both data are distributed near a straight line, and the results of the K-S test are acceptable.



**Figure 4.** Q-Q diagram of GDP



**Figure 5.** Q-Q diagram of Population density

Therefore, from table 4, we can give the acceptable health range for both in terms of normal distribution.

**Table 4.** Weights of Indicators

| Indicator                | Upper Bound | Lower Bound |
|--------------------------|-------------|-------------|
| GDP                      | 1.67E26     | 2.38        |
| Total fresh water        | -           | 11.34       |
| Agricultural land        | -           | 20.46       |
| Forest coverage          | -           | 12.59       |
| Land and sea area        | -           | 5.06        |
| Loss of fixed capital    | 2.4E11      | -           |
| Agricultural value added | -           | 4.61E9      |
| Use of renewable energy  | -           | 1.22        |
| Energy depletion         | 1.6E10      | -           |
| Mineral depletion        | 3.06E9      | -           |
| Forest depletion         | 9259307     | -           |
| Population density       | 84.55       | 62.91       |
| Greenhouse gases         | 644558      | -           |
| PM2.5 in air             | 27.96       | -           |
| Area of the reserve      | -           | 16.96       |
| Red list index           | 1           | 0.78        |

### 3.4. Diagnosis of Health Conditions

We use a simple acceptance/rejection model (0-1 model) to determine the health conditions. The overall health condition can be measured with point gain and the occurring problem can be located. For each indicator  $i$ , if the value falls in the range of GGDP, the point  $p_i = 1$ , otherwise  $p_i = 0$ .  $\omega_i$  is the weight of indicator  $i$ . We calculated the point gain with the equation below:

$$OPG = \sum_{i=1}^{16} \omega_i p_i \quad (8)$$

$$GGDP = GDP \times EHI \quad (9)$$

Economic health index (EHI) describes the GGDP condition of a system, but only when its value is 1 can it prove that the system is completely proper. If the EHI value is too low, it means that the GGDP of the country has at least one main indicator or a large number of secondary indicators that are wrong.

We have classified the health status as follows:

- Good:  $EHI = 1$ , showing that all indicators are normal.
- Sub-good:  $EHI \geq 0.9$ , showing that the system has small problems.
- Not good:  $0.6 \leq EHI < 0.9$ , showing that one or more main indicators are wrong, which can be improved.
- Extremely not good:  $0.4 \leq EHI < 0.6$ , showing that the overall problem of the system is serious, and more reasonable construction of higher education is needed.
- Serious:  $0.2 \leq EHI < 0.4$ , showing that the higher education system is seriously out of balance and cannot perform its normal functions.
- Bad:  $EHI \leq 0.2$ , showing that the country has no higher education system.

### 3.5. Climate Model Realized by Using Markov Chain

After each country uses GGDP instead of GDP as a measure of economic health, as we choose the indicator's health range for each indicator, governments will introduce relevant policies to take corresponding measures to promote the growth of GGDP, which is like GDP, except that the aspects that are focused on are much changed and increased. In the future, the "unhealthy" indicators will

move closer to the "healthy" ones. However, our hands can only provide the direction of change; efficiency cannot be specified. In this case, we consider the implementation effect of policies later changed by the GGDP influence as a stochastic process. To facilitate subsequent modeling, we make the following assumptions based on general assumptions.

- One of the three states of the implementation model per year: good, poor, or counterproductive. If the politics are effectively implemented, the indicator will change rapidly and approach its expected value. Still, if the policy is not effectively implemented, the indicator state will remain the same or even worse.

- The state that occurs in the following year depends on the current state and the value of the current indicator. If the policy worked well in the previous year, it would be easier to implement in the following year. In addition, the closer the current indicator is to its normal value, the weaker the effect of the policy will be. This assumption considers the degree of unhealthy indicators versus the degree of unhealthy indicators and the role of the policy. The less healthy the indicator is, the stronger the willingness to implement the corresponding policy and the greater the acceptability of countries. On the contrary, if the indicator reaches the health limit, the effect of politics will be less noticeable.

- Under the control of the policies, unhealthy calculated metrics will eventually reach normal values. These policies are flexible. As the effect decreases due to its proximity to normal values, the policies are appropriately adjusted, and finally, the indicators will converge to normal values. We use the above assumptions to build the model and determine the Markov chain<sup>[10]</sup> to predict the indicator's trend under the policy's influence. We consider the policy implementation effect (PIE) and buffer (BU) as the factors determining the current state, which are random variables with the following distribution. Since the difference between the present value and the health value of the indicator (DCH) affects the policy intensity, we add it to the distribution function of PIE to represent its effect. The distribution laws of PIE and BU are shown in the table 5.

**Table 5.** Distribution law for modeling parameters

| Last state        | PIE   | BU    | Distribution law                                    |
|-------------------|-------|-------|-----------------------------------------------------|
| Good              | $X_1$ | $Y_1$ | $X_1 \sim N(K \times DCH - 0.01), Y_1 \sim N(0.01)$ |
| Poor              | $X_2$ | $Y_2$ | $X_2 \sim N(K \times DCH), Y_2 \sim N(0.01)$        |
| Counterproductive | $X_3$ | $Y_3$ | $X_3 \sim N(K \times DCH + 0.01), Y_3 \sim N(0.01)$ |

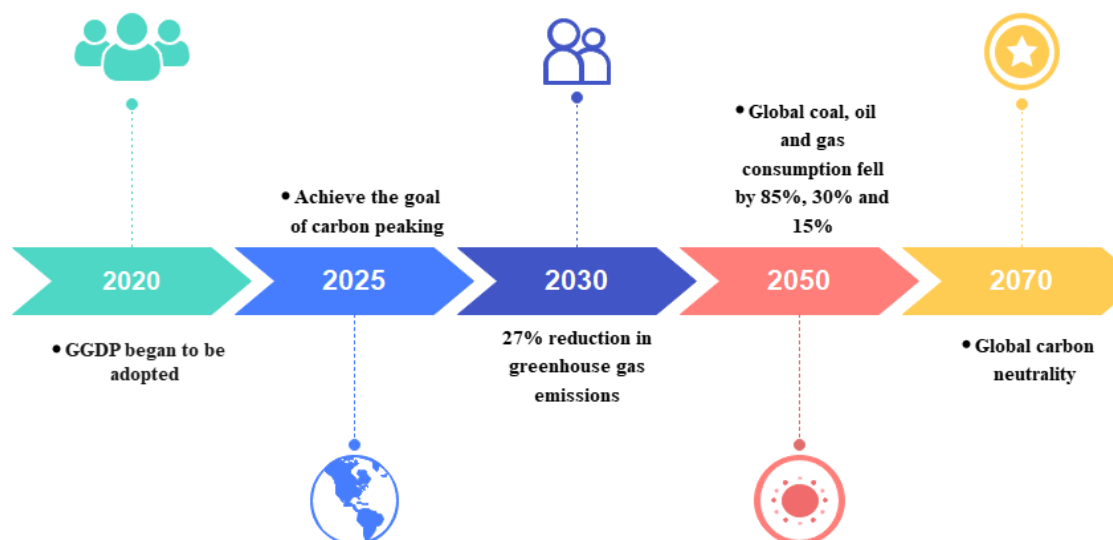
The variable  $k$  is used to control the severity of the value change. It varies from indicator to indicator. As for modeling, if  $X + Y > 0.05$ , it indicates that the policy is in good state. If  $X + Y < 0.05$ , it indicates that policy has counterproductive effect. With the discussion above, we can use the indicator value of the  $i$ -th year to determine the value of the  $(i + 1)$ -th year, and the transfer equation can be given in the following form:

$$value(i + 1) = value(i) \times (1 - (X + Y)) \quad (10)$$

### 3.6. The Paris Agreement

The Paris Agreement, a climate change agreement signed by 178 parties worldwide, is suitable for global action to address climate change after 2020. The long-term goal of the Paris Agreement is to limit the global average temperature to less than 2 degrees Celsius compared to the pre-industrial period and to work towards limiting the temperature increase to less than 1.5 degrees Celsius.

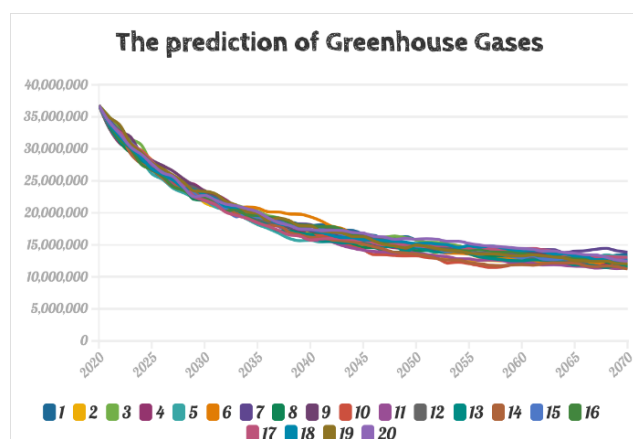
A more specific timeline is shown in figure 6.



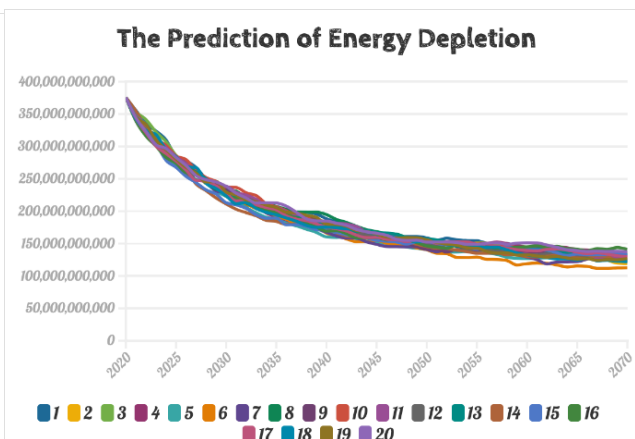
**Figure 6.** Timeline for the Paris Agreement

### 3.7. Climate Impact Timeline

Based on the above model, we forecast the achievement of the targets agreed upon in the Paris Agreement. We selected the changes of two indicators, greenhouse gas emissions, and energy depletion, for all countries separately to reflect global climate change, as shown in figure 7 and figure 8.



**Figure 7.** The prediction of GHS



**Figure 8.** The prediction of Energy depletion

After 20 independent iterations of the experiment (different curves in the graph), we find that GHG emissions have reached an average reduction of about 40% by 2030, exceeding the target and reaching a healthy level by 2070. And energy depletion lives up to expectations, with an average reduction of 60% in 2050, well in line with the target. With the GGDP criteria, the vision of the Paris Agreement seems more achievable and has been realized.

## 4. Conclusions

This study focuses on the impact of the Green GDP (GGDP) accounting system on climate change. The research team developed a reliable model to assess the fiscal health of countries using GGDP and encouraged governments to adopt policies for mitigating the environmental impact of economic development. The model incorporated raw data from 50 countries between 2010 and 2020, considering factors such as GDP, resource consumption, environmental degradation costs, and ecological damage. The researchers applied the Analytic Hierarchical Process (AHP) to determine the weights of each factor and introduced the concept of the Economic Health Index (EHI) to represent the actual health of an economy.

Markov chains were also used to predict the future global climate impact of flexible government policy measures promoting GGDP growth. The study considered the achievement of greenhouse gas (GHG) emissions and energy consumption targets set in the Paris Agreement to measure the effect on global climate. The paper described the GGDP accounting method, which included components such as gross domestic product, environmental degradation costs, and ecological damage. It also introduced other related models like GeGDP and MEWGDP that adjusted GDP to account for resource depletion costs, environmental degradation costs, leisure time, unpaid work, and environmental damage. The study proposed five main factors to measure the health of an economy: Heart (GDP), Resource (e.g., freshwater, agricultural land, forest coverage), Expense (e.g., energy depletion, population density), Emission (e.g., greenhouse gases, PM2.5), and Diversity (e.g., area of the reserve, red list index). The researchers selected indicators for each factor and used weighting analysis to determine their relative importance. To evaluate the health status of countries, the researchers selected data based on the 80% quartile as the healthy range for positive and negative indicators, while considering the distribution pattern for interval indicators. The study also presented a list of selected countries for analysis. The paper then described the GGDP health model and the climate impact model. The GGDP health model utilized the weighted analysis of indicators to rank their importance and determine overall health. The climate impact model used Markov chains to predict the future global climate impact based on government policy measures promoting GGDP growth. Overall, this study provides insights into the development of the GGDP accounting system and its potential effects on climate change mitigation. It offers a comprehensive framework for assessing the fiscal health of countries and predicting their climate impact.

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